EPSC Abstracts
Vol. 6, EPSC-DPS2011-420-1, 2011
EPSC-DPS Joint Meeting 2011

Deformation and splitting of asteroids by YORP spin-up

C. Comito (1,2), A. Thirouin (3), A. Campo Bagatin (4,5), P. Tanga (2), J.L. Ortiz (3), D.C. Richardson (6)
(1) INAF/Osservatorio di Torino, Italy (2) Laboratoire Cassiopée UMR 6202, Université de Nice Sophia- Antipolis, CNRS, Observatoire de la Côte d'Azur, France (comito@oca.eu) (3) Instituto de Astrofísica de Andalucía-CSIC, Spain (4) Departamento de Fisica, ISTS, EPS - Universidad de Alicante, Spain (5) Insitituto Universitario de Física Aplicada a las Ciencias y la Tecnología, Universidad de Alicante, Spain (6) Dept. of Astronomy, University of Maryland, USA

Abstract

We explore the dynamics of rotating gravitational aggregates by a gravitational N-body code based on hard spheres. In particular, we address the problem of satellite formation due to fission of a parent asteroid. Our simulations show that significant asymmetries can be produced in the asteroid shapes during a YORP spin-up process, eventually leading to fission into two or more components. In some cases the creation of a bound binary system is observed. In contrast to previous models we are able to simulate the direct binary formation, without passing through intermediate steps of mass shedding and reaccumulation. Also, we investigate a higher rotation regime, under the hypothesis that asteroids can sustain a certain stress due to a non-negligible internal cohesion. Different possible evolutions are presented, creating a broad spectrum of cases to compare with the real data.

1. Introduction

The internal structure of asteroids is generally unknown, but a study of their rotation states and shapes can shed light on the possible fragmented nature of their interiors [3],[2],[11]. Understanding the origin of multiple systems is part of this effort. It also constitutes a major challenge of the outmost importance, given the number of additional constraints (such as masses and densities) that this category of objects can provide.

The YORP effect, a torque exerted upon an object due to an uneven thermal emission, can be responsible for the spin up of small asteroids and the eventual formation of binaries ([12]). [13] have shown that, while increasing their angular momentum, flattened spheroids can experience mass shedding from the equator. This process can put a certain amount of fragments on low orbits, where they can eventually reaccumulate by mutual collisions into a satellite.

We successfully explored two alternative routes:

- passing through a gradual deformation, under YORP spin-up, that is capable of leading directly to a satellite formation by fission of the parent asteroid. The conditions under which this fission is reproduced in our simulations are investigated.
- a high angular momentum regime, reached through the assumption that a certain amount of internal cohesion can prevent an asteroid to breakup at its limit corresponding to no cohesion.

2. The numerical model

Our gravitational aggregated asteroids are thus represented by a collection of N=1000 hard particles held toghether by gravity. We evolve the system by *pkdgrav*, an efficient N-body code capable of solving collisions among hard spheres. The internal kinetic energy is dissipated by using a coefficient of restitution lower than unity for inter-particle collisions.

The spheres have a radius of r_s =50 m and a density $\rho_s = 3000$ kg/m^3 although some tests are performed at higher r_s for comparison. Given the random sphere packing, the resulting bulk density is $\rho_b \sim 2000$ kg/m^3.

3. Slow YORP acceleration

Several initial shapes are considered: elongated ellipsoids, drop-shaped, axysimmetrical flattened (MacLaurin) spheroids, and overall irregular shapes, to study their relevance for the subsequent evolution. We start our simulations with spins and angular velocities just below the centrifugal breaking limit.

To simulate a slowly operating YORP acceleration, we gradually increase the asteroids' overall angular momentum by 1% at fixed time intervals, while monitoring the evolution for reshaping and fissioning events.

As the bodies reshape to adapt to their new conditions, a quantity of material can be emitted when the angular momentum exceeds the breakup limit (see also section 4 for the $\overline{L}$ limit at ~ 0.45). While many ejected single particles easily escape the primary (and are discarded after each step), occasionally a big clump separates from the primary and remains in a closed orbit: this usually appear as a *budding* event, where a slight prominence from the parent asteroid gradually grows and detaches.

The initially closed orbits have generally very high eccentricity (>0.8), and easily lead to lost secondaries by spin-orbit forces. As a result, in some simulations a secondary is formed on an orbit with apocentre within 50 primary radii, inside the Hill sphere beyond ∼0.5 AU from the Sun. In some cases the secondary is lost in a few orbits. In the other simulations the secondary/primary mass ratio is always <20%, resulting in a satellite escape, in agreement with the semi-analytical results of [5].

4 High Angular Momentum shattering

In [11] we analysed the reshaping mechanisms of a population of ellipsoidal objects set at different initial angular momentum L and arbitrary axis ratios.

As seen in previous works ([10, 11]) and from section 3, there appears to be a limit for the dimensionless angular momentum $\overline{L}$ ([4]) between 0.4 and 0.45 above which cohesionless objects composed of rigid spheres cannot re-accumulate or mantain cohesion (except ad-hoc cases). It is possible that in many real-world cases some objects possess a small internal cohesion allowing them to accumulate an above-threshold spin prior to yielding.

To simulate this, we use a variety of ellipsoidal shapes (the same as in [11]), starting them with rigid-body rotation at high (0.5 and above) initial $\overline{L}$. The numerical simulations are then started putting the objects in circular orbit around the Sun at 2.5 AU.

Two main kinds of secondary systems result. a) Massive emission from the equator: the asteroid starts near the MacLaurin sequence of flattened spheroids, and tends to rapidly lose matter from the equator, forming a dense cloud of material orbiting a highly reshaped remnant. b) Fissioning objects: the asteroid starts far from the classical hydrostatic equilibrium shapes and tends to rapidly separate into two (or more) similarly sized objects.

The process is intrinsically chaotic; particularly in the second case, where the chances of formation of two unbound objects are not negligible. The fate of these systems cannot be accurately predicted. Most often, the systems are on highly eccentric orbits, that can easily be driven either towards stability or to a hyperbolic orbit via strong mutual interactions.

The resulting binaries tend to maintain a memory of the initial $\overline{L}$ content, and objects starting at $\overline{L} = 0.6$ have the same final $\overline{L}$ as a number of stable (synchronous) binaries in the Main Belt with similar secondary/primary mass ratios.

5. Summary and Conclusions

The simulations presented here are a starting point for an extended N-body approach to the physics of small bodies into the domain of binary formation. We can reproduce a variety of situations from which binaries can emerge that, based on the correspondence with the real objects, provide an indication of the possible binary-formation scenarios. We intend to go further with some analytical calculations to study the reliablilty of long-term simulations, and to predict the stability and evolution of the obtained binaries.

CC and PT have been supported by the French Programme Nationale de Planetologie. DCR acknowledges support from Grant No. NNX08AM39G issued through NASA's Office of Space Science.

References

[1] M.J.S. Belton et al., 1996, Icarus 120-1, p185

[2] W.F. Bottke et al., 2005, Icarus 175-1, p111

[3] A. Campo Bagatin et al., 2001, Icarus, 149-1, p198

[4] S. Chandrasekhar, 1969, Ellipsoidal figures of equilibrium, New Haven and London, Yale University Press

[5] S.A. Jacobson, D.J. Scheeres, 2011 (in press), Icarus

[6] S.C. Lowry et al., 2007, Science 316, p272

[7] P. Michel et al., 2002, Icarus 160-1, p10

[8] P. Pravec, A.W. Harris, 2007, Icarus 190-1, p250

[9] D.C. Richardson et al., 2005, Icarus 173-2, p349

[10] P. Tanga et al., 2009, PSS 57-2, p183

[11] P. Tanga et al., 2009, APJ Letters 706, p197

[12] P.A. Taylor et al., 2007, Science 316, p274

[13] K. Walsh et al., 2008, Nature 454, p188